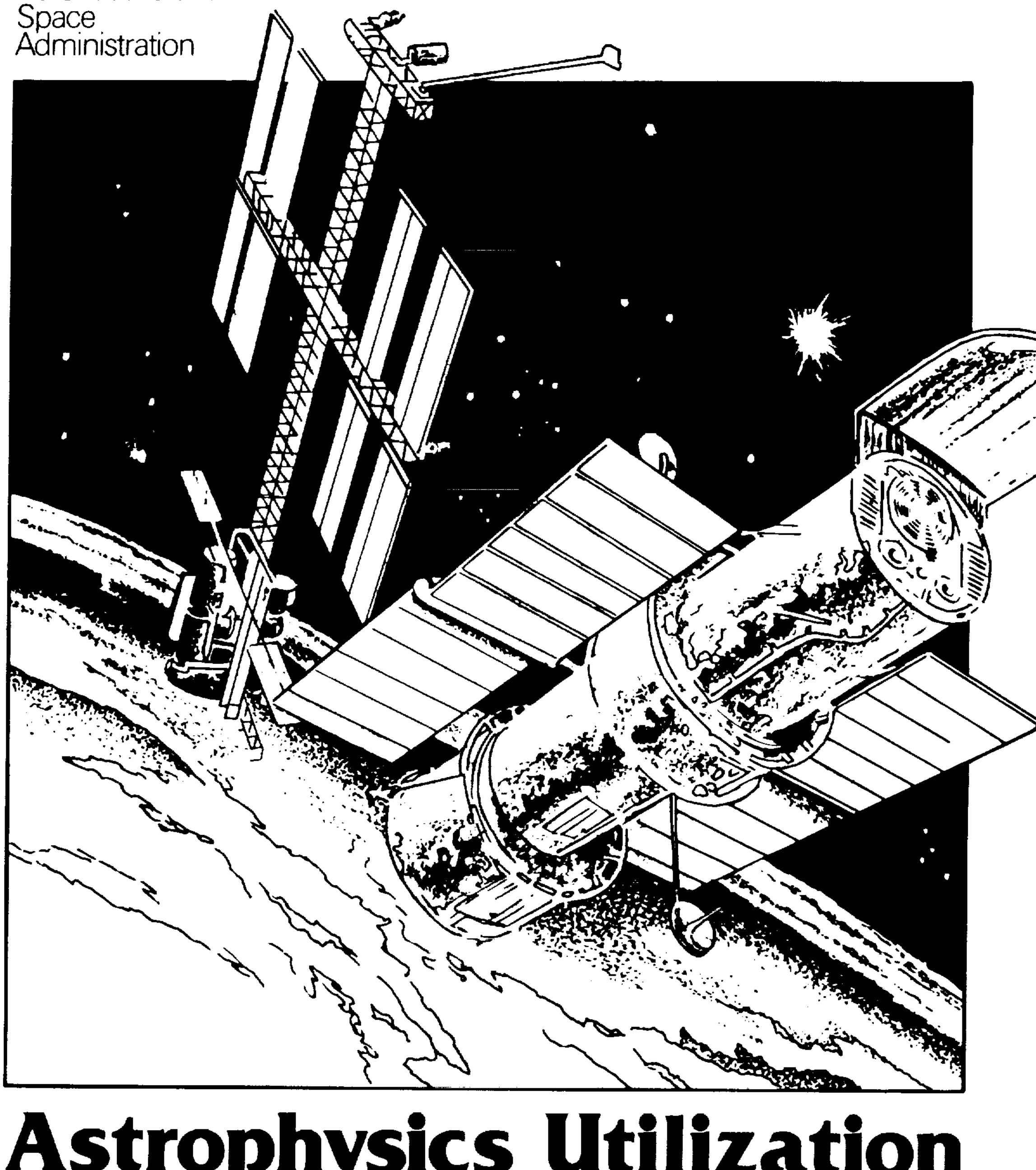
Volume 4
Assembling Astrophysics Missions at the Space Station

National Aeronautics and Space Administration



Astrophysics Utilization of the Space Station

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ASTROPHYSICS AND THE SPACE STATION

VOLUME 4

ASSEMBLING ASTROPHYSICS MISSIONS AT THE SPACE STATION

A major advance in our ability to study and understand our universe was achieved when we were able to place astrophysical telescopes and instruments in space, above the obscuring presence of Earth's atmosphere. The advent of the Space Shuttle offered new capabilities for carrying astrophysical payloads into orbit. The Hubble Space Telescope, for example, was sized to make optimal usage of the Space Shuttle's carrying capabilities.

The Space Station era will open even broader vistas for such astrophysical observations. No longer will the sophistication and performance of spaceborne instrumentation be limited by weight and volume constraints imposed by the carrier vehicle. In-orbit assembly and construction will eventually make achievable and practical spaceborne observatories many times the size that can be accommodated by the Space Shuttle. Already, the need for a Large Deployable Reflector (LDR) more than 10 meters in diameter has been identified by the National Academy of Sciences as the major orbiting observatory for submillimeter astronomy. Such large observatories will advance present capabilities by orders of magnitude, making possible observations across the electromagnetic spectrum that will penetrate to the very edges of the universe with both high spatial and spectral detail. In-orbit assembly and construction is expected to be an evolving capability of the Space Station. The likely evolutionary stages of the Space Station capabilities will include servicing (e.g., monitoring and material change-out, maintenance and repair), payload checkout and integration to orbital maneuvering or transfer vehicles, and assembly and construction. Without the Space Station, many of these operations will be costlier, less productive, or simply impossible. Once the Space Station servicing capability is mature, in-orbit assembly becomes a logical step of capability.

To provide an early perspective on astrophysics requirements for in-orbit assembly in conjunction with the Space Station, four missions have been selected as being representative of the range of astrophysics missions that will require such assembly: the Large Deployable Reflector (LDR), the Coherent Optical System of Modular Imaging Collectors (COSMIC), the High Energy Space Station Array (HESS Array), and the Gamma Ray Imaging Telescope System (GRITS). The success of these missions will depend critically upon a Space Station that includes in-space, in-orbit assembly facilities by the end of the 1990's. This volume describes the hardware and objectives of the missions and develops assembly scenarios for the hardware.

LARGE DEPLOYABLE REFLECTOR (LDR)

The Large Deployable Reflector (LDR), planned for the late 1990's, is an observatory to observe electromagnetic wavelengths in the submillimeter and far infrared range. It will be placed in a low Earth orbit that will permit the LDR to operate over a portion of the electromagnetic spectrum (30 to 1000 microns) that is completely obscured by the Earth's atmosphere. The LDR will have to be at least 20 meters in diameter to achieve the angular resolution needed for many of LDR's most important scientific investigations at these wavelengths. Because these dimensions exceed the capabilities of the Shuttle bay, and because the projected mass for the system may exceed the Shuttle capacity, the LDR must be either folded to fit into the Shuttle bay or transported with more than one Shuttle launch for subsequent assembly in orbit.

Figure 4.1 is an artist's rendering of the Large Deployable Reflector. The present concept is a Cassegrain system (with the focus behind the primary mirror), with a primary reflector having a focal length equal to its diameter. This design is straightforward and has minimal optical aberrations over a narrow field of view. The science instrument package and focal plane assembly are located behind the vertex of the primary reflector to maximize the structural rigidity.

LDR Size Requirements

The size of LDR is driven by requirements for angular resolution and instrument sensitivity. One of LDR's main scientific problems will be to investigate the cold, dense regions of dust and molecular gas where stars are formed. These regions are highly structured, leading some stars to form in orbiting pairs and some to form planets. How? To find out, we will have to observe with sufficient angular resolution to discern the structure and with sufficient sensitivity to determine the state of the molecular gas, its excitation, density, magnetic fields, and velocity throughout the region.

A good illustration can be made with Figure 4.2, the Whirlpool Nebula, a nearby galaxy with a pronounced spiral structure connected in a suggestive way to a smaller companion galaxy. With the angular resolution of this picture, about 1 second of arc, we can see that the bright regions of the spiral arms are right next to some very dark lanes of dust that completely absorb the light from the stars as they form. We suppose that our own galaxy is a spiral like this, only not so striking. The only way we can investigate the overall pattern in a spiral galaxy is to get a top view as shown; the results help us interpret what we observe about our own galaxy from the inside.

While the resolution of the picture in Figure 4.2 is good, it is easy to see that to learn about the events inside the dust lanes, we have to have the capability for angular resolution at least this good. For LDR, this means a telescope diameter of 20 meters.

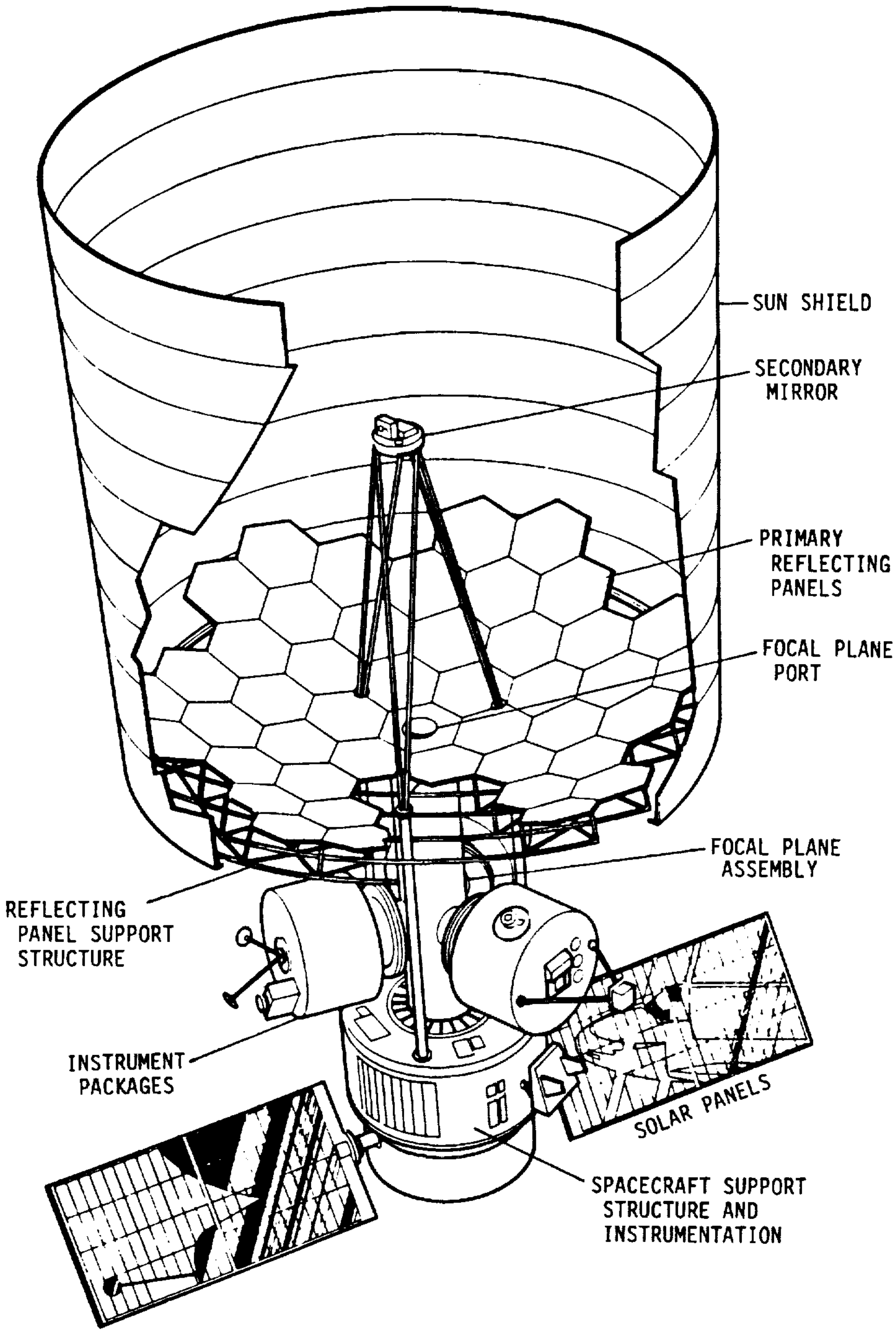

FIGURE 4.1. THE LARGE DEPLOYABLE REFLECTOR (LDR)

With its primary mirror 20 meters in diameter, LDR will require assembly in space. LDR will provide submillimeter spectroscopic observations that will complement the sensitive imaging of the Space Infrared Telescope Facility (SIRTF).

Equally important for LDR is high sensitivity. Molecules radiate at discrete frequencies that uniquely identify the molecule and its state of excitation. The velocity of the gas is typically a few hundred meters per second, causing a shift of only one part per million in the frequency we observe. While LDR will have this spectral resolution and more, it is clear that if we divide the radiation into a million frequency channels, tremendous light-gathering power is needed to make up the sensitivity lost in the division by the spectrometer.

A National Academy of Science Recognized Need

It is the significant scientific content of infrared and submillimeter astronomy that compels us to find a way to develop LDR. Star formation is thought to proceed in a cascading chain of events, starting as interstellar

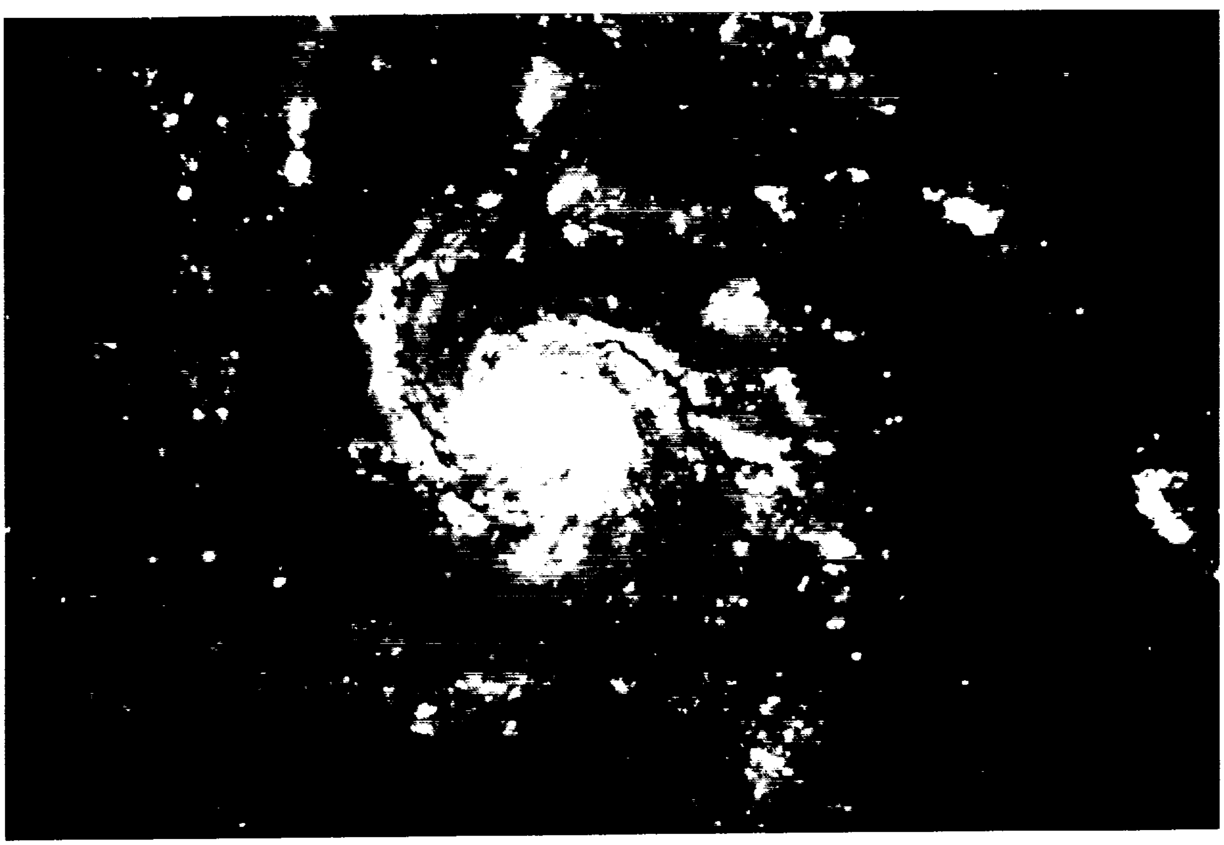

FIGURE 4.2. THE WHIRLPOOL NEBULA (M-51)

The resolution of this picture is approximately 1 arcsecond. LDR must be large to resolve the formation of stars.

winds and shock waves (that we are far from understanding) sweep up gas from the space between the stars and collect it into giant molecular clouds. The process continues with the collapse of the clouds and the formation of dense disks out of which stars and planets finally form.

This is the theory, in any case, and it predicts that the best way to investigate the physical process of birth in astrophysics will be in the submillimeter and infrared wavelengths. This is recorded in the recommendation of the Astronomy Survey Committee of the National Academy of Science report Astronomy and Astrophysics for the 1980's. It ranked LDR as one of the four major new observatories recommended for development in this decade.

Spectroscopic LDR Complements Imaging SIRTF

The temperature of the telescope does not matter so much at high spectral resolution. The radiation of the heat from LDR's mirror will be divided into more than a million channels of frequency as we examine the narrow bands of emission from molecules rotating and vibrating in response to forces in interstellar space. In each channel, the background will be very low.

For sensitive imaging, however, as much radiation as can be gathered from the source has to be put into a single wide channel. In sensitive imaging SIRTF will excel with its telescope cooled to within a few degrees of absolute zero. This low temperature allowed IRAS to make the first far infrared maps of the sky in its pioneering mission. Even with a primary mirror only 1 meter in diameter, SIRTF will be more sensitive than LDR for many investigations of quasars and active galaxies, dust surrounding stars in birth and stars near death, and the small particles around stars like Vega that are clearly related (in a way we do not yet know) to the formation of planets.

Structure and Assembly of the LDR

The reflecting surface will consist of individual panels mounted on a rigid structure with actuators to adjust the individual panels in orbit. Because of the limited size of the Shuttle cargo bay, the panels will be limited to a 4-meter crosswise dimension. The technical requirements for the LDR include the following:

- Primary mirror diameter of 20 meters
- Primary mirror made up of 20-200 individual rigid panels supported by a truss backup structure
- Panels of 1-3 meters in diameter
- Instrument package mounted behind vertex of reflector
- Eight focal-plane instruments requiring 3-4 cubic meters total volume
- Total system mass of 25,000-50,000 kilograms
- Instrument cooling to temperatures of 1-100 K required

- Reflector cooled passively to 150-200 K
- Orbital altitude of 700 kilometers
- Fifteen-year orbital lifetime, with periodic revisits to the Station for instrument and cryogenic replacement
- Thermal shade 22 meters in diameter and 25-30 meters in length required
- Optical surfaces protected from contamination
- 5-10 kilowatts power.

One possible assembly scenario for LDR calls for preassembling portions of the primary reflector truss with the actuators and reflector panels attached. These preassembled modules would be sized to fit in the Shuttle cargo bay. Once delivered to the Space Station, the modules would be stored until all the modules have been delivered. The assembly facilities would then be used to take the individual modules and connect them. Other LDR systems would similarly be broken down into pieces that would easily fit in the Shuttle and then be assembled at the Station. This scenario would allow efficient packaging in the Shuttle and would eliminate the cost of developing expensive deployment mechanisms.

Another possible assembly technique--one that more fully exploits the Space Station capability--is one that uses an Assembly and Transport Vehicle (ATV). With a trusswork platform in a low-contamination area of the Space Station, the construction would begin by attaching a module containing the focal-plane instruments and various other observatory instruments to the Space Station by means of a support structure that would permit the instrument module to pivot about its centerline. The astronauts would construct the primary mirror by assembling the support structure in sections and attaching control actuators and hexagonal mirror facets to the substructure as each section is completed. The pivoting instrument module would permit the astronauts to assemble the mirror with only simple, moderate movement of the manipulator arms of the ATV. After the primary mirror was in place, the sunshade would be partially assembled around the hexagonal primary mirror; the support structure for the secondary reflector would then be erected. The remaining portions of the sunshade would then be assembled, completing the construction of the LDR. The system would be checked out with the LDR still attached to the Space Station. After checkout, an Orbiting Maneuvering Vehicle would be attached to the LDR, and the observatory would be propelled into a higher orbit.

Construction of the LDR at the Space Station would relieve many of the design constraints that would apply if the LDR had to be designed to be transportable in a single Shuttle flight.

COHERENT OPTICAL SYSTEM OF MODULAR IMAGING COLLECTORS (COSMIC)

In its most studied configuration, COSMIC is an array of eight telescopes along a system structure 36 meters long and 4 meters in diameter. Like the Large Deployable Reflector, it is driven to large size to gain angular resolution and sensitivity--this time in visible and ultraviolet light. Unlike LDR, COSMIC uses an array of telescopes as an interferometer.

To understand this difference, we start with a familiar imaging system. LDR's aperture will be completely filled with mirror panels except for a small hole at the center to let the infrared and submillimeter radiation back to the instruments. The hole is small and has no effect on the resolution of the image formed on the instruments; if the hole were made larger, the only effect would be to make the image fainter.

COSMIC carries this to an extreme, deleting almost all of the mirror panels to form an array of telescopes connected by a precise optical system, as illustrated in Figure 4.3. By combining the light from the telescopes along paths that are kept equal, COSMIC achieves all the angular resolution of a telescope 36 meters in diameter, but only in the long dimension of the array. The full performance of a telescope 36 meters in diameter is synthesized by rotating COSMIC about the line of sight.

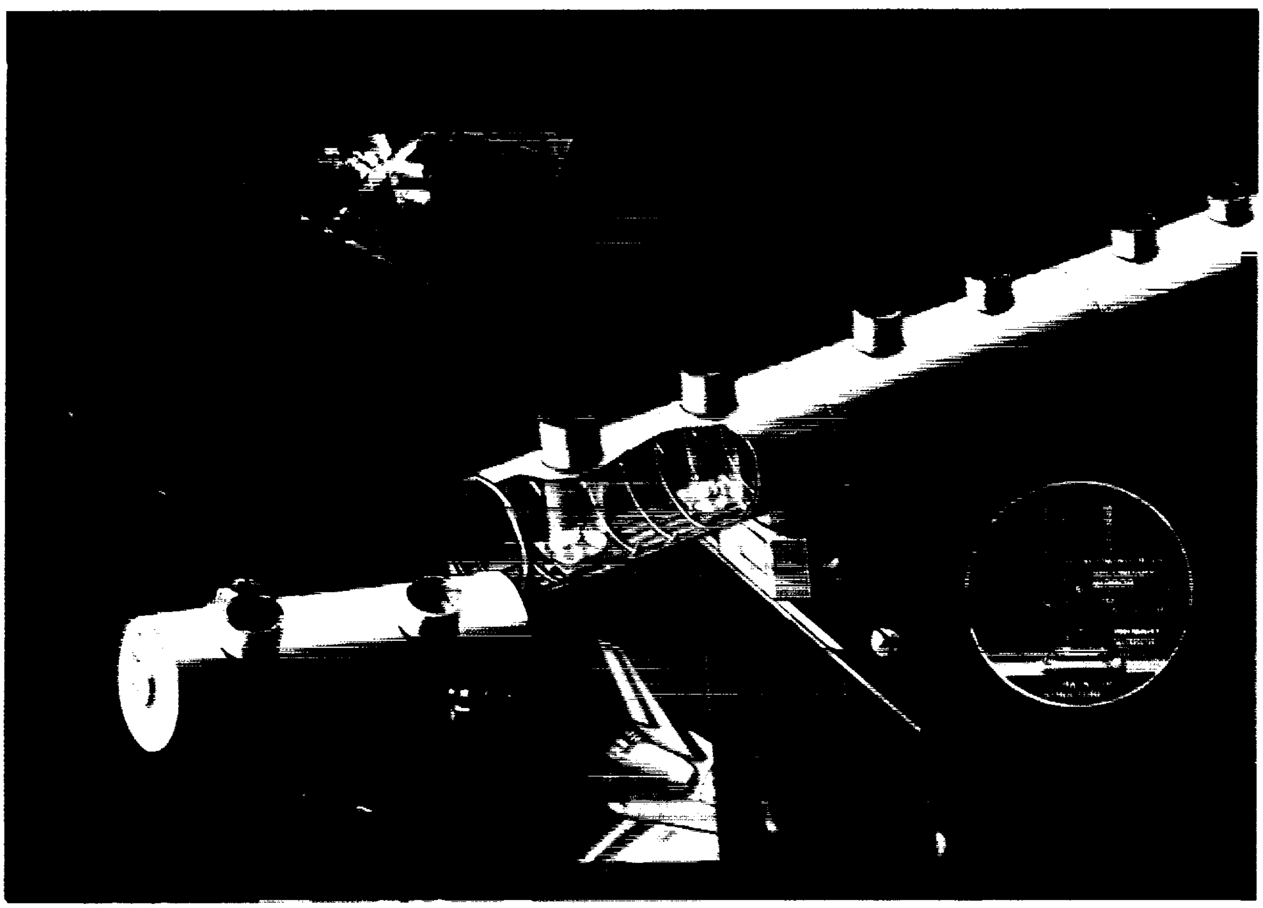

FIGURE 4.3. COHERENT OPTICAL SYSTEM OF MODULAR IMAGING COLLECTORS (COSMIC)

Space assembly is also required for this system, which will give the angular resolution of a visible-light telescope 36 meters in diameter.

ORIGINAL PAGE
COLOR PHOTOGRAPH

COSMIC Size Requirements

Currently, the sharpest pictures we have of any objects come from arrays of radio telescopes ganged together like the optical telescopes of COSMIC. While the best ground-based optical images are typically smeared to be no sharper than 1 arc-second by the twinkling we see in stars, by combining the signals in radio telescopes on opposite sides of the world, images a thousand times sharper have been obtained. What they have seen is a universe in constant motion, illustrated in Figure 4.4. There, a blob of luminous material is ejected from the central core of the quasar 3C 273. What is especially remarkable about these images is that the blob appears to move away from the quasar at a little over the speed of light.

But what is the blob? What can it tell us about the quasar that ejected it? Figure 4.4 shows the emission at radio wavelengths which are sensitive to very energetic electrons in magnetic fields, but quasars also emit visible and ultraviolet light in the discrete frequencies of highly excited atoms. Are they excited as the blob goes by? Are they part of the blob? These spectral lines contain a wealth of information, but we need to know how they are excited before we can interpret them. There appears to be no way to find out without achieving, in visible light, the resolution comparable to that in Figure 4.4. We will need a 36-meter interferometer to distinguish the blob from the quasar.

The image resolution and sensitivity of COSMIC would also be used to investigate the surfaces of nearby supergiant stars. On some of these stars, the advanced stages of nuclear combustion have turned the outer layers into giant, boiling masses of gas. Images of these surfaces are expected to show complex, exaggerated motions that may reveal a better understanding of the structure of all stars, including the Sun.

COSMIC will also be used to study contact binary stars that orbit each other so closely that they almost touch. In these objects, gas from one star is pulled off by the gravity of its companion to produce a complex atmosphere governed by gravitation, radiation, kinetic energy, and magnetic fields. Until now, what is known about these objects has been learned from their spectra; with COSMIC, the flow could be observed directly and examined over time to ascertain the specific effects of these forces.

In our own solar system, the surfaces of Pluto and its recently discovered moon Charon could be surveyed, and COSMIC would be used to image the rings of Saturn with resolution similar to that achieved by Voyager. In addition, COSMIC could provide a detailed look at the nuclei of comets to observe their activity as heat from the Sun drives surface material into the comet's coma and tail. Finally, we expect to be able to learn a great deal about the "solar wind" by using COSMIC.

Structure and Assembly of COSMIC

The design concept of COSMIC has been optimized for transport on the Space Shuttle. It is composed of modules 18 meters long and 4 meters in diameter, containing all optical systems fully assembled. These modules would completely fill the Shuttle bay and would be joined together as they are brought up. Mechanical, electrical, and optical connections would then be made, and optical alignment and telemetry systems would be checked out.

Many of the fine or critical adjustments may exceed 1 week and thus would not be possible if the Space Shuttle alone were involved; they would require an extended stay at the Space Station. Such activities would include coarse-alignment verification, thermal stability checks, and verification of mechanisms, as well as structural position adjustments to fine-tune the optical alignment.

Being manned, the Space Station could provide better opportunities and greater flexibility in activities such as attaching additional solar panels, opening and extending Sun shades, replacing aging components (such as gyros, electronics, and batteries), replenishing expendables (such as gas for control jets), and refurbishing the focal-plane instrumentation. Furthermore, the prospect of space assembly permits entirely new packaging concepts that promise greatly reduced costs. A good example is the erection of light shade baffles which may be assembled without regard to conventional launch-load design requirements, thereby lowering cost through reduced structural load requirements.

The COSMIC concept has evolved based on the Space Shuttle as the assembly and transportation system. With the development of the Space Station as a permanent, manned facility in space, many of the limitations of volume, weight, and orbital staytime imposed by the Shuttle have been removed.

HIGH ENERGY SPACE STATION ARRAY (HESS ARRAY)

The Space Station will make possible a mission to obtain the spectrum and composition of the rarest and most energetic cosmic rays. The central portion of HESS Array is a massive set of detectors assembled from 256 identical modules, each measuring 16 centimeters by 16 centimeters by 2.5 meters. Each module contains a thick layer of a solid scintillating material and a thin tungsten layer. The scintillator produces a signal proportional to the amount of ionization caused by the cosmic ray particles, and the tungsten provides additional stopping power. The stacked modules form the calorimeter, a cube approximately 2.5 meters on a side capable of measuring the energy of cosmic rays incident from any direction.

Between each layer of 16 modules, there is room for a tray of passive detectors for studying nuclear interactions of these extremely energetic cosmic rays. Figure 4.5 shows the modules stacked to form the body of the calorimeter.

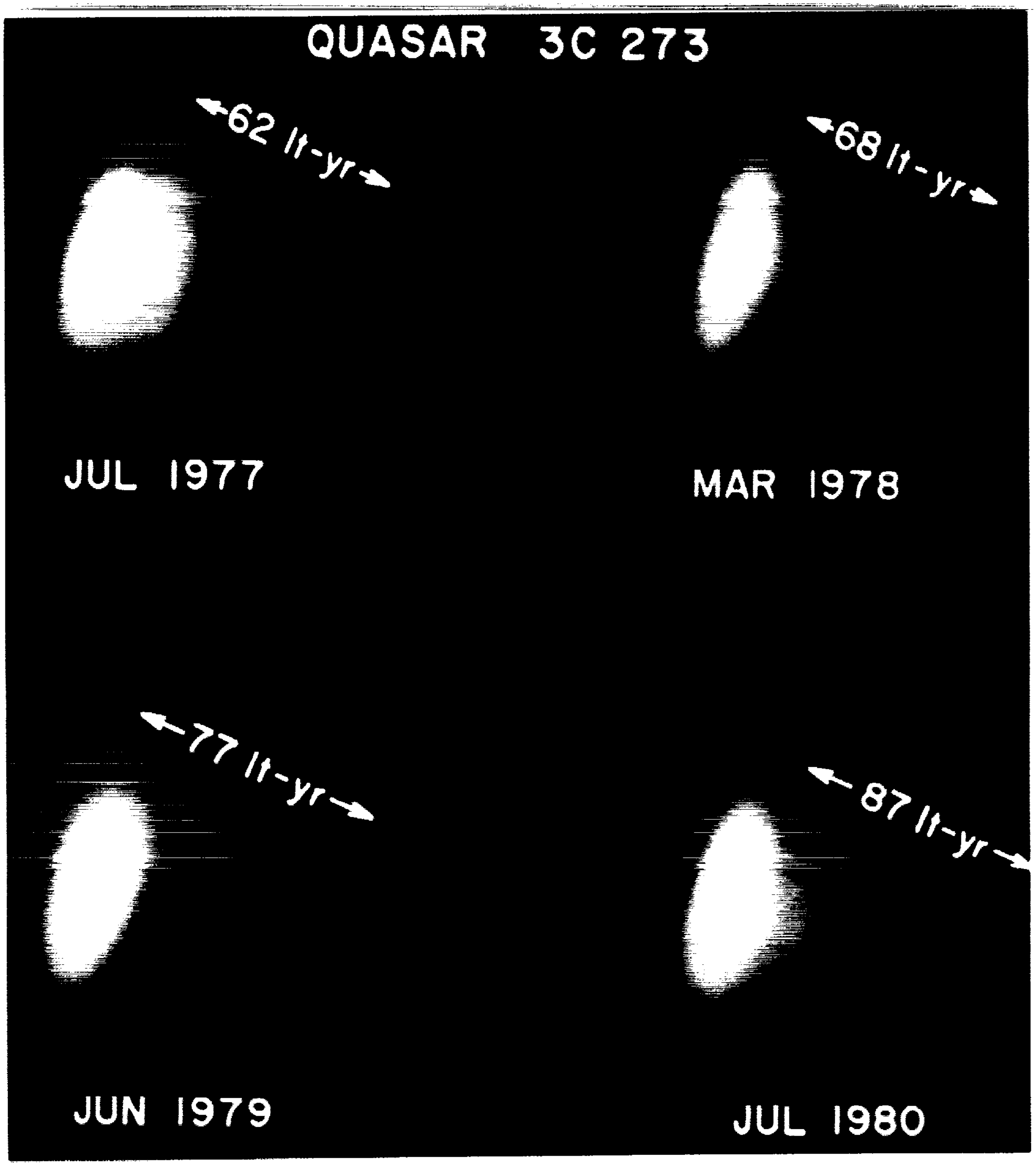

FIGURE 4.4. RELATIVISTIC EJECTION OF MATTER FROM QUASAR 3C 273

The motion of the blob of relativistic electrons appears to exceed the speed of light. COSMIC must be very large in order to resolve distances of tens of light-years in such sources as 3C 273, whose distance from Earth is about 15 percent of the distance across the entire universe.

Since the central body of the calorimeter is not capable by itself of identifying the incident particles, the exterior surfaces of the calorimeter cube will be covered with charge-sensitive detectors. A 4 x 4 module array would be used to cover each surface of the calorimeter except the bottom. These modules could be mounted on a hinged frame which could be swung out of the way when access to the calorimeter modules was desired.

HESS Array Size Requirement: Stopping Cosmic Rays

The High Energy Space Station Array (HESS Array) mission is not too large to fit into the Shuttle bay whole, but it is far too massive to be lifted whole by the Shuttle. This mass is needed to stop cosmic rays, which have energies greater than 10^{16} electron volts (eV). Electron volts are a convenient measure of energy for nuclear particles because these particles typically have only one or at most a few times the charge of an electron, so

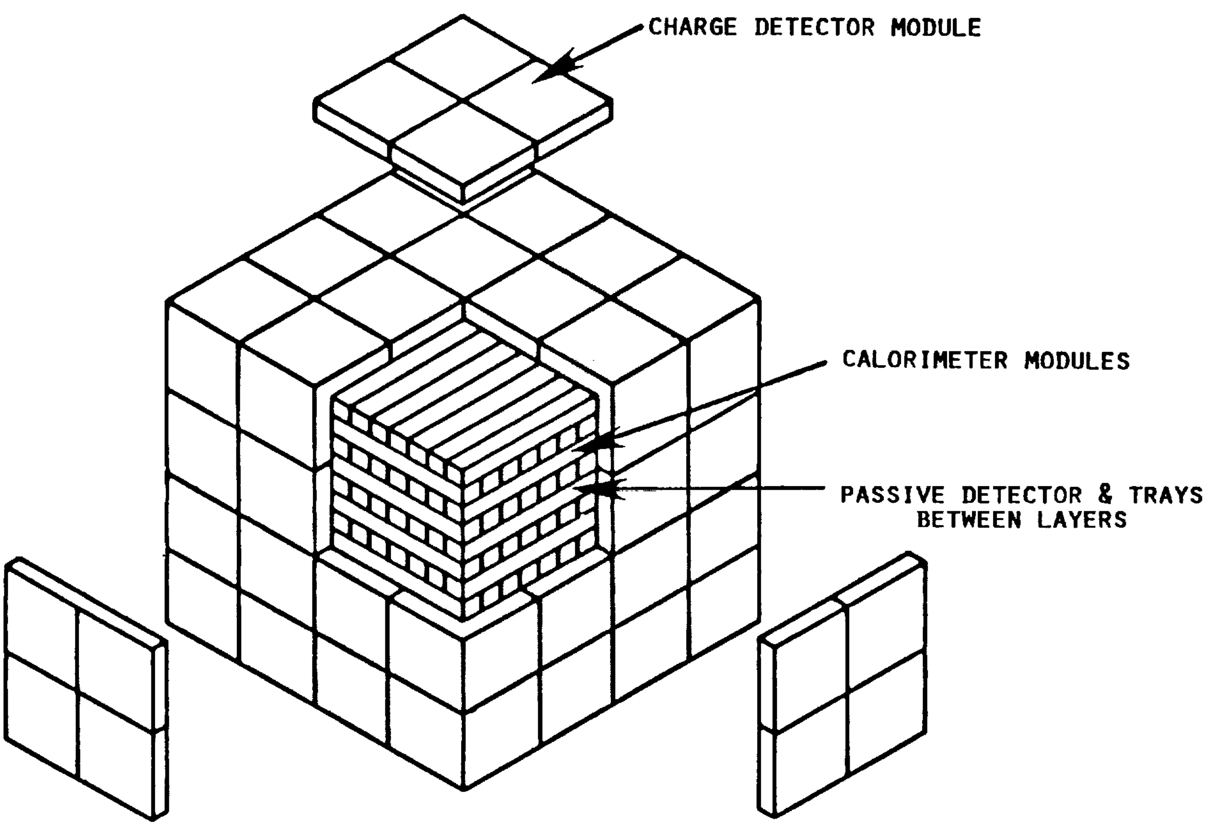

FIGURE 4.5. HIGH ENERGY SPACE STATION ARRAY (HESS ARRAY)

The large size and great mass of the HESS Array are needed to observe extremely rare and energetic cosmic rays that carry an important signature of their acceleration.

we know that they have been accelerated through a potential of about 10^{16} volts before arriving at earth.

This is not to say that a single immense electric field in interstellar space accelerates the cosmic rays. Probably, the acceleration occurs in many small, random steps to produce the distribution we observe with many more cosmic rays at lower energies than at higher energies. The oldest question in high energy astrophysics, in fact, concerns how cosmic rays get their enormous energies.

The answer appears to be held at the highest energies--the energies that HESS Array is designed to observe. One reason that HESS Array is so large is that particles with this much energy can transmit their energy far into massive objects they encounter.

The cosmic rays themselves do not travel beyond their first nuclear collision, but in that collision they can generate dozens of secondary particles, many of them exotic and highly unstable, which go on until their first nuclear collision to produce another generation of particles--each parent sharing its energy with the particles of the next generation in a cascading shower that only ends when all the energy has been dissipated in ionizing the calorimeter's counters.

HESS Array Size Requirement: Rarity of Cosmic Rays

The cascading shower of energy also develops in the atmosphere, and arrays of detectors on the ground have observed showers that must have been generated by particles having as much 10^{21} electron volts. For perspective, note that 10^{21} eV is one Joule (the energy needed to lift one gram more than one meter) contained in a single atomic nucleus arriving at the Earth. The energies of 10^{13} to 10^{16} of interest for HESS Array are also quite large, especially when compared to the energy contained in the mass of the particle, $E=mc^2$. For a proton, the nucleus of a hydrogen atom, this energy is just about 10^9 eV--completely negligible compared to the energy expended accelerating the particles to velocities so close to the speed of light.

However, the more energetic the cosmic rays, the rarer they are. HESS Array is scaled to be large enough to observe a critical reduction ("bend") in the distribution of cosmic rays that occurs at about 10^{15} eV. It is the composition of the cosmic rays, the number of protons in the nucleus, that will tell us whether shock waves, generated by supernova explosions traveling in low-density regions of hot interstellar gas, are primarily responsible for accelerating the cosmic rays.

This current theory incorporates elements of several earlier theories--energy from supernovae and acceleration in the interstellar medium. It is important to note that the best theory of 5 years ago, that cosmic rays come directly from supernova explosions, failed to predict the composition observed by cosmic ray instruments on the third High Energy Astronomy Observatory (HEAO-3).

In the current theory, the efficiency of acceleration breaks down when interstellar magnetic fields can no longer contain the cosmic rays close to the shock front, and the energy where this occurs depends on the charge and on the mass. There will be a characteristic signature in the composition at these energies, if the current theory is right.

The following table shows the expected number of events observed by HESS Array above various threshold energies in 2 years of operation at the Space Station.

The numbers in the table are adequate to provide a definitive picture for our understanding of the acceleration mechanism, and they will enable us to reach the energy at which a break in the spectrum is expected and to tell, by comparing the energy at which the break occurs for protons and helium nuclei, what type of mechanism is operating to produce it.

EXPECTED NUMBER OF EVENTS TO BE OBSERVED
ABOVE THRESHOLD IN TWO YEARS

	Threshold Total Energy (eV/Nucleus)		
Particle Type	10^{14}	10^{15}	10^{16}
Hydrogen	50,000	1,000	20
Helium	26,000	5,200	10
Carbon, oxygen	11,000	220	4
Neon, magnesium, silicon	8,400	170	3
Iron	13,000	260	5

Structure and Assembly of HESS Array

Assembling HESS Array in orbit will be much simpler than assembling LDR or COSMIC. Each 100-kilogram module will be designed as a self-contained unit, completely checked out on the ground. With a flexible packaging concept, the modules could be brought to the Station on Shuttle launches whenever space is available. Each module would be fitted with guidepins and simple latches so that when it was removed from the crate, it could be snapped into place in a lightweight holding fixture on the Space Station. Each module would be hooked onto the previous one as the crates were unloaded, eliminating the need for intermediate storage facilities. Modules would then be plugged into support electronics attached to the mounting frame. By the time several layers of the detector were in place, data-taking could begin.

As currently envisioned, HESS Array will need 16 square meters of Space Station structure with a clear, continuous view of space. It will also need 1000 Watts of power, 100 kbits/sec downlink telemetry, assembly and servicing capability, and temporary storage. The storage area would have to be maintained at about 20 C and have a volume of approximately 20 x 20 x 300 centimeters to accommodate a locker for the target material. The expected mission lifetime includes 1 to 2 years for construction and 5 to 10 years for operation.

GAMMA RAY IMAGING TELESCOPE SYSTEM (GRITS)

The Gamma Ray Imaging Telescope System (GRITS) will observe gamma rays with energies of more than 100 MeV. When gamma rays of this very high energy get close to the nucleus of an atom, they can convert virtually all their energy into an electron and an anti-electron pair moving at nearly the speed of light. The pair also goes in very nearly the same direction as the incoming gamma ray and the main components of GRITS will work to measure the direction of flight of the particle-antiparticle pair.

As presently conceived, GRITS will use an expended Shuttle External Tank as its basic structure. Behind a thin target for converting the gamma rays into pairs, an external tank will be filled with pressurized gas. Light travelling through the gas does not go quite as fast as light in a vacuum. For GRITS, the gas used will have a pressure such that the electrons and anti-electrons will be travelling faster than the speed of light in the gas. The result will be like a jet that breaks the sound barrier. Light will be given off in a trail behind the particles, reflected in a mirror at the rear of GRITS, and observed with sensors at the front of the telescope to determine the direction of flight.

Primary Mission of GRITS

Like cosmic rays, the higher the energy of the gamma rays, the fewer there are to observe, and because there are very few gamma rays at energies greater than 100 MeV, very large detectors must be used to locate the sources in a reasonable period of time. Even larger detectors are needed to be able to find out when more (or fewer) gamma rays are arriving.

In many cases this variability in number carries the significant information about a source. The pulsar in the Crab Nebula has a rotational period of only 33 milliseconds--so short that only a neutron star could remain intact at such a rapid rotation rate. This pulsar has been observed to pulse in x-rays, visible light, and gamma rays, all with the same period. For each of these types of radiation, the pulses appear at precisely the same time during the period. In the case of the gamma rays, however, the brightness of the second pulse has been gradually declining while the first pulse has remained constant. GRITS will be able to tell us what is happening in this very unusual object. At very high energy levels (above 2,000 MeV), gamma rays are so energetic that they do not need the strong electric field of an atomic nucleus to create electrons and antielectrons; they can create pairs in the magnetic field of the pulsar. Small changes in the strength of the field will have a large effect in the intensity of the gamma-ray pulses. GRITS will need to be very large if it is to determine variations in the number of very-high-energy gamma rays.

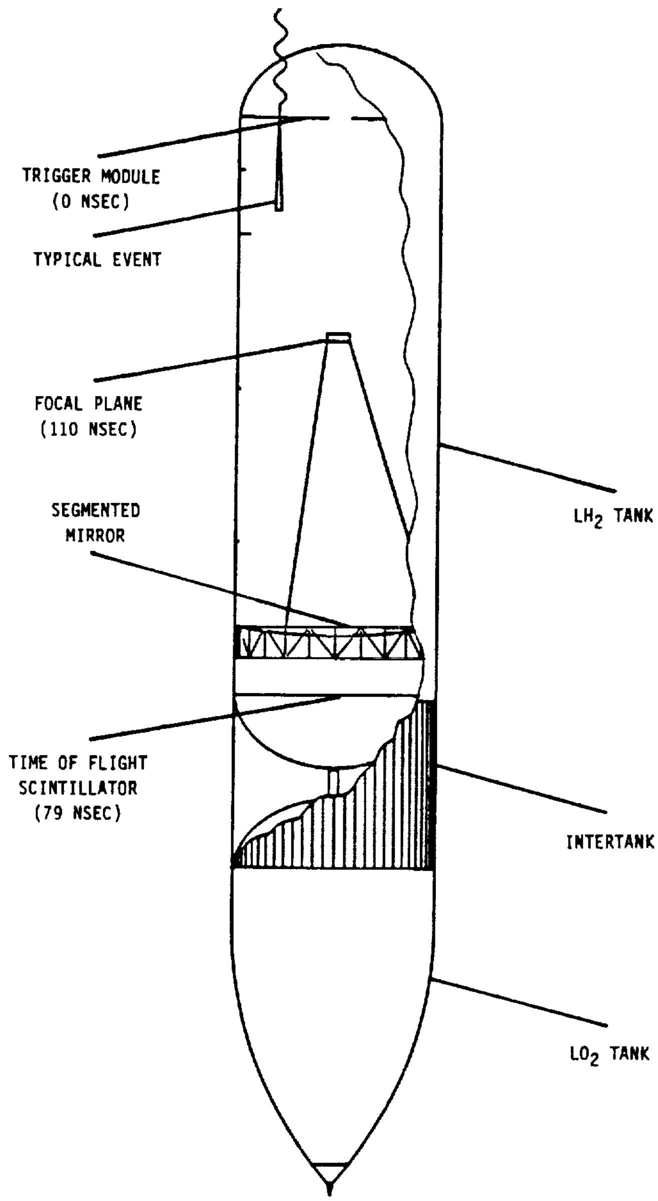

FIGURE 4.6. GAMMA RAY IMAGING TELESCOPE SYSTEM (GRITS)

Although very high energy gamma rays are rare, they provide essential information about the most energetic objects in the universe. GRITS uses a Shuttle external tank to hold its large-area sensing system.

Structure and Assembly of GRITS

The external tank would be prepared on the ground with special fittings of a meteoroid shield and an aluminum lattice support structure for the segmented mirror. The tank would be carried along with the Shuttle to the Space Station. With the telescope and subsystem components being carried in the payload bay, all the necessary components would be delivered in one Shuttle flight.

Two assembly methods are possible. In the first, the entire inner apparatus can be installed during extravehicular activity. In the second, a docking adapter can be built into the tank; a tunnel could then be connected to the pressurized portion of the Space Station, and the tank could be reconfigured in a "shirtsleeve" environment.

Because structural strength is not critical in weightless conditions, the inner instrumentation can be attached by Velcro or push pins to a thin sheet stretched across the interior of the tank. Likewise, the mirror segments can be installed with lightweight snaps, and the tank can then be sealed and pressurized. Spacecraft subsystems can be installed on the inside or outside of the tank to make it an autonomous, free-flying observatory.

SPACE STATION REQUIREMENTS

In space construction, there will always be a major trade-off decision between automatic deployment and man-assisted assembly. At one extreme is the automatic deployment of a folded structure. The expanded structural size is then limited by the ingenuity used in packaging the structure and by the cargo capacity of the Shuttle; in this case, the deployment mechanisms must be extremely reliable, and the requirement for efficient packaging leads to complex joint designs, limited truss member lengths, and strut components with hinge breaks. In contrast, erectable structures are easier to pack, and although they take more steps to construct in space, the structure will be stronger. In addition, astronauts will be available to take corrective actions during assembly. Because erectable structures generally can be expected to be stiffer, greater geometrical precision is possible and less active control is needed to maintain the structural shape. For this reason, erectable structures are favored for astrophysics applications, in which optical alignments are critical.

Because of its permanent, manned status, the Space Station would be an ideal base for manpower and resources to construct these missions in space. Although the Shuttle could provide the same services, its limited stay-time in orbit could not provide the manpower, time, or resources that would be required for space assembly of these astrophysics missions spacecraft.

Following is a set of general requirements that the Space Station must meet if it is to handle the assembly scenarios described earlier. However, these missions are far enough in the future that they can be adapted to many possible changes in the Space Station's design. These requirements are merely an attempt to define standard accommodation capabilities for the Space Station. Space Station assembly capabilities are applicable not only to sophisticated missions like LDR, COSMIC, HESS Array, and GRITS but also to the assembly of much simpler payloads, such as those described in Volume 5.

Assembly and Storage Areas

Space must be adequate for assembling large payloads and temporarily storing parts and partially finished structures that are awaiting completion. The general requirement is for space outside the Station, but the possibility of assembly in a "shirtsleeve" environment is very desirable. Initially, this pressurized volume may be part of a Space Station module, but later a large workspace, 20-30 meters in diameter, could prove to be efficient and cost-effective for large assembly missions. Any internal assembly workspace will have to allow for the transfer of assemblies that are nearly as large as the workspace itself.

Standard Interfaces and Resources

The mission equipment interfaces to the Space Station for data, fluids, power, thermal connections, and communications should be standardized to Space Station systems. Standard interfaces will make the Space Station more adaptable, as more and more payloads will use them.

Mobility

The Space Station must provide a means to transport and manipulate crew, material, and equipment around the assembly area. A vehicle could be attached to an assembly boom structure and provided with manipulators. For example, some Space Station plans include an Assembly and Transport Vehicle (ATV), a movable platform to be used in construction and to extend and maintain the Station. The vehicle would be attached to the Space Station truss structure and would let the astronauts move around fairly freely during extravehicular activity to move Station modules, modify structure and components, and perform maintenance. The ATV will be tremendously valuable for in-orbit construction of astrophysics missions like LDR, COSMIC, and HESS Array.

A space crane attached to the vehicle would be used for positioning payloads while the astronauts work on them. As robotics increase in sophistication, mobile assembly devices can evolve to a fully teleoperated system, leading to increased productivity in construction and servicing in space.

Storage and Docking Facilities

The Space Station must have the capability to move large items from the Shuttle and provide storage space for them until assembly. At least one storage facility should be able to accommodate an item, such as a spacecraft, that completely fills the Shuttle bay.

EVA Capability

There must be a capability for extended extravehicular activity with high mobility and the capability to use special tools and test equipment in space.

Lighting and Power

Lighting must be provided so that assembly would not be restricted or determined by orbital position or time. The Space Station may also have to provide power and cooling for the payloads being assembled, during their test and checkout periods. Manipulating equipment and operating assembly tools will also require electrical power.

Environment

The Space Station environment must not contaminate the payloads. Consequently, the Space Station must be able to isolate payloads from such things as volatiles that may corrode or condense on optics, electromagnetic interference, and vibration. Although many payloads can adapt to variations in the Space Station's environment, the Station's external assembly space should be as far as possible from major contamination sources.

Orbital Transportation Services

The Space Station must be able to provide transportation for large payloads (25,000-50,000 kilograms) to higher orbits at low acceleration. These transportation services must also be able to retrieve and deliver assemblies to near-Station orbits as required.

SUMMARY

As has been seen in this volume, the Space Station will be an essential part of the future of astrophysics. The capabilities provided by the

Station for assembling large structures in space will allow for efficiencies in design that are not possible with the Space Shuttle alone. Missions such as COSMIC, with its lengthy and critical optical alignment requirements, could not be accomplished without the extended stay time that would be provided by the Space Station. The LDR, which requires a great deal of volume in the Shuttle's cargo bay and repeated trips before it can be usable, will be more efficiently assembled in space at the Space Station. Other missions, such as the HESS Array, could not be economically accomplished without the Space Station as they have a mass larger than a single Shuttle flight could carry into orbit. The Space Station is therefore a needed capability for the advancement of astrophysics.

WORKSHOP ON

ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on

Assembly of Astrophysics Missions at the Space Station

Mr. Micheal Kiya, Chairman

Dr. Paul A. Cooper
Mr. Thomas M. Crabb
Mr. Maurice Dubin
Dr. Kenneth Frost
Dr. Daniel Gezari
Mr. James Grady
Dr. Herbert Gursky
Mr. Peter Jones
Mr. Max Nein
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